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PARTITIONING ENERGY REQUIREMENTS OF ANGUS, CHAROLAIS AND RECIPROCAL CROSS COWS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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This educational experience has been inspiring, fulfilling and humbling. I have learned that a realistic objective approach with an open mind is an invaluable asset.

VLA

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PREFACE

Increasing energy costs have stimulated more interest in efficient use of our natural resources. Utilization of energy in agricultural enterprises needs to be critically evaluated for economic survival of the enterprise. Feed energy required for beef production comes largely from harvested and unharvested forage and grasses that constitute a high proportion of the costs of maintaining a cow. These costs have increased along with other production inputs.

Beef cattle producers need to know how total feed energy is utilized in order to increase their efficiency (Turner, 1974). Cow herd efficiency is extremely important, especially the energetic efficiency of various size groups (Gregory, 1972; O'Mary and Dyer, 1972). Knowing the proportions of feed required for maintenance, growth of body tissue and production will assist the progessive producer in evaluating the efficiency of his cattle (Hohenboken et al., 1972).

Energy intake can theoretically be partitioned into requirements for maintenance of body weight, growth of tissue and production of animal products. It does not, however, lend itself to direct experimental solution (Hohenboken et al., 1972). An indirect statistical approach was first presented by Brody and Proctor (1935) in which TDN (total digestible nutrients) consumed during lactation was regressed on 4% fat-corrected milk, weight change and weight at parturition to the .73 power.

In the present study, an attempt was made to partition TDN consumed during different stages of production into requirements for maintenance, weight change and milk production. Three methods of developing prediction equations employed mean weight, mean weight with regression line forced through the origin and mean weight to a calculated exponent in the multiple regression analysis.

Total energy intake of beef cows has been reported by several researchers (Klosterman et al., 1968; Marshall et al., 1976; Shake and Riggs, 1975; Turner, 1974). Annual energy requirements of a cow vary from 1556 kg TDN for small Hereford cows in Missouri averaging 407 kg (Turner, 1974) to 2297 kg TDN for 2- to 4-year-old Angus x Charolais cows in South Dakota (Marshall et al., 1976).

Partitioned energy intake has been reported by fewer researchers. Hereford cows from 210 days of age through the third parity utilized 73% of TDN intake for maintenance, 6% for weight gain and 21% for milk production during a 240-day lactation (Hohenboken et al., 1972). Mature lactating Holstein and Jersey cows utilized 49.5% of TDN intake for maintenance, 1.3% for growth and 48.9% for milk production (Brody and Proctor, 1935). Maintenance energy is the largest partition of energy consumed. Requirements for maintenance need further evaluation for beef cows varying in size and maintained in different climates.

Technically, maintenance energy is the amount of food energy needed to support an animal without gaining weight, losing weight, doing work or yielding product (Turner, 1974). An animal is essentially producing heat as a function of the basic metabolic process. Early nutritional research showed that heat production (HP) was not closely related to body weight (BW) for species varying in size from rats to cattle (Church and Pond, 1976). Researchers felt a need for some overall "law" that applied to animals in general for measuring HP. In general terms, HP varies with surface area which affects heat loss (Church and Pond, 1976). Changing posture of individuals and different biological types of cattle may affect surface area, but surface area generally varies with BW to the .67 power (Church and Pond, 1972). HP also varies with BW to an exponent, so metabolic weight which is associated with HP (Thonney et al., 1976) was defined as BW to a fractional power (Church and Pond, 1972).

The value of the exponent used with body weight to calculate metabolic weight has been a subject of controversy. Some of the early estimates were given by Brody and Proctor (1935) who suggested .734 in work with dairy cows. Kleiber (1961) reported .756. Winchester and Hendricks (1953) calculated .67 as the exponent in work with beef calves. In 1966, the National Research Council adopted .75 as the exponent used with body weight to calculate metabolic weight. This single value may vary with individuals or species but has the practical advantage of rapid calculation (Maynard and Loosli, 1975).

The value of a single exponent for describing metabolic weight has been questioned for its range of applicability. Recognizing the natural variation in all biological systems, it is inappropriate to apply one numeric value to all situations (Thonney et al., 1976). Work of other researchers cited by Thonney et al. (1976) resulted in exponents ranging from -.338 (Hashizume et al., 1966) for Japanese Black Breed cows to 4.96 (Blaxter and Wainman, 1961) for steers. The exponent of .75 was developed from data for species varying widely in weight. Effects other than weight peculiar to each species or stage of production were ignored. Simply using body weight would be more appropriate and serve adequately as a covariable (Thonney *et al*., 1976). Thonney *et al*. (1976) further suggests that the regression line calculated from a linear equation should include an intercept. Neville (1971, 1974) and Neville and McCullough (1969) regressed maintenance requirements on BW with the regression line forced through the origin. Towner (1978) used $BW^{.75}$ with an intercept in partitioning TDN for twin calves. Hohenboken *et al*. (1972) used $BW^{1.00}$ with an intercept for predicting TDN requirements for lactating Hereford cows.

Least squares calculation of the best fitting regression line for the data can be done with or without the zero intercept parameter. Forcing the line through the origin is an artificial constraint that may produce biased estimates of TDN requirements. In this case, the zero intercept regression line may not be the best fitting, as it is required to rotate at the mean to satisfy the imposed conditions.

This study compared prediction of daily TDN requirements using three variations of mean body weight (MWT) in multiple regression analysis. MWT as measured ($MWT^{1.000}$), MWT to a calculated exponent (MWT^{x}) and MWT with the regression line forced through the origin (zero intercept) were substituted in the regression model.

Population

Cows used in this study were Angus, Charolais and reciprocal crosses born in 1970-1972. This is the same population described by

Marshall et al. (1976). At weaning, heifers were randomly allotted by breed to a pasture or drylot management system. Pasture females were managed under traditional summer grazing and winter feeding conditions. Drylot females were randomly allotted by breed to individual inside pens for feeding.

Management of drylot cows was consistent from year to year. Weighed amounts of feed were offered to drylot cows in their pens twice daily, and calves were allowed to nurse during feeding. Creep feed was offered *ad libitum* to calves in the same individual pens during the night. Cows and calves were separated outside during the day. Cows were weighed after an overnight shrink every 28 days. The amount of feed offered drylot cows was individually adjusted in an effort to simulate weight change for half sib, age, parity, breed group contemporaries on pasture. Data for this study were taken from drylot cows and calves from weaning 1970 through weaning 1978. Subclass frequencies are given in table 1.

Feeding

After weaning in 1970, heifers entering the experiment were offered daily 2.27 kg corn silage and a pelleted mixture (Starter Pellet I) of 24.7% oats, 24.7% alfalfa hay, 7.4% corn grain, 9.1% soybean meal, 7.4% molasses and 1% Durabond *ad libitum*. On May 6, 1971, 1.36 kg chopped alfalfa hay was substituted for corn silage and the pellet formulation changed to 24% corn cobs, 27% corn grain, 29% oats, 12% alfalfa hay, 7% molasses and 1% Durabond (Starter Pellet II). Alfalfa pellets replaced starter pellet II on November 9, 1971, at a rate of 4.54 to 8.40 kg per

TABLE 1. SUBCLASS FREQUENCY[a] OF EXPERIMENTAL FEMALES

Age	Breed of dam AA	AC	CA	CC	Total
2	19	16	17	7	59
3	16	11	16	9	52
4	10	11	13	8	42
5	14	9	14	12	49
6	15	9	13	7	44
7	10	4	6	3	23
8	7	4	2	2	15
Total	91	64	81	48	284

[a] Frequency indicated by number of complete annual records for cow, calf and individual feeding.

head per day based on condition. This ration was fed until the first calving in the spring of 1972. Heifers weaned in 1971 and 1972 entering the study were fed 1.36 to 4.09 kg chopped alfalfa hay per day, alfalfa pellets ad libitum and cracked corn based on condition until first calving. After first calving, drylot cows were offered chopped alfalfa hay, alfalfa pellets, cracked corn or ground ear corn in amounts indicated in table 2. Energy values for feeds used are given in table 3.

During the winter, pasture cows were fed to maintain their weight during mid-gestation and gain .5 kg per day during late gestation. After calving, cows were fed to maintain postpartum weight before going to pasture.

TABLE 2. DAILY FEED OFFERED INDIVIDUALLY FED BEEF COWS

Time	Chopped alfalfa hay (kg)	Alfalfa pellets (kg)	Cracked shelled corn[a] (kg)	Ground ear corn[a] (kg)
Calving '72 to weaning '72	2.72	(2.72 - 8.17)[b]	(1.82 - 4.54)	
Weaning '72 to weaning '73	2.72	(2.72 - 8.17)	(1.36 - 4.54)	
Weaning '73 to weaning '74	(2.72 - 4.08)	(4.54 - 8.17)		(.91 - 9.53)
Weaning '74 to weaning '75	4.08	(4.54 - 9.07)	(1.36 - 3.63)	
Weaning '75 to weaning '76	4.08	(2.27 - 9.52)	(1.36 - 3.63)	
Weaning '76 to weaning '77	4.08	(4.08 - 9.07)	(2.72 - 3.63)	
Weaning '77 to weaning '78	4.08	(3.17 - 9.98)	(2.27 - 3.63)	

[a] Offered only during lactation.
[b] Parentheses indicate range from lowest to highest.

TABLE 3. ENERGY VALUE OF FEEDS

Feed	International number	TDN[a] %
Corn silage	3-08-153	70.00
Starter pellet I	--	70.79
Starter pellet II	--	80.90
Alfalfa pellets	1-00-111	57.00
Chopped alfalfa hay	1-00-063	55.00
Corn grain	4-02-931	91.00
Ground ear corn	4-02-849	90.00

[a] Calculated on dry matter basis from NRC for Beef (1976).

The limiting feeding method used for individual drylot cows was a means of quantifying energy intake. Energy consumption was based on pasture cows grazing improved bromegrass, reed canarygrass and sudan pastures. TDN was essentially limited only by dry matter content of forage grazed, gut fill and rate of passage.

Although energy density was greater in feeds offered drylot cows, the proportion of TDN from each of the forage and concentrate portions of the ration was similar to rations used by Hohenboken et al. (1972) and Neville (1974). Cows use higher energy density rations more efficiently (Church and Pond, 1972), resulting in reduced energy requirements. Drylot cows received little exercise compared to pasture cows, further reducing energy requirements. Predicting energy requirements for pasture cows may be slightly underestimated due to increased efficiency of the drylot ration and reduced exercise for the drylot cows.

Data Analysis

Data were analyzed for the cow year extending from weaning to weaning and for three subdivisions within the cow year based on stage of production (Clanton and Zimmerman, 1970). Period 1 was during mid-gestation, extending from weaning to 90 days prior to calving. Period 2 or late gestation was the 90 days prior to calving and Period 3 or lactation was from calving to weaning. The heifer year extended from weaning of the experimental females to weaning the following year. Least squares procedures were used to analyze data from the heifer year, cow year and three periods within the cow year.

Independent variables considered in the analysis were selected based on potential influence on the dependent variable TDN. Independent variables considered in Period 1 were MWT; weight change from start to end of the period (WTC); age of dam in years (AOD); breed of dam (BOD) coded 1 for Angus (AA), 2 for Angus x Charolais (AC), 3 for Charolais x Angus (CA) and 4 for Charolais (CC) cows; year (YR); previous parity (PP) coded 0 for open and 1 for weaning a calf the previous year; number of days in the period (DAYS) and all two factor interactions. Three factor and higher order interactions were assumed unimportant. Period 2 independent variables considered were MWT, WTC, AOD, BOD, YR, PP, sex of calf (SEX) coded 1 for bulls and 2 for heifers, birth weight of the calf (BWT) and all two factor interactions. Variables considered in Period 3 were MWT, WTC, AOD, BOD, YR, SEX, DAYS, future parity (FP), milk production (MILK) and all two factor interactions. FP was coded 0 for open and 1 for cows calving the following year. MILK was the sum of four daily totals taken at spaced intervals during lactation. In analysis of the cow year, all previously considered independent variables were used except DAYS and interactions with DAYS. Variables considered in the heifer year analysis were MWT, WTC, YR, BOD and DAYS.

The purpose of the initial analysis of variance was to reduce the number of variables to only those of interest and those influencing TDN consumption ($P<.25$). Main effects and interactions within respective periods were deleted using a step down procedure. Variables were removed if analysis resulted in probability of an F value greater than .25. Residuals for variables of interest were taken from the final reduced analysis of variance models for multiple regression analyses.

Multiple regression analyses were conducted using residuals of variables as data. MWT was evaluated as one of the independent variables affecting TDN consumption using three different techniques. $MWT^{1.000}$, MWT^{x} and zero intercept were substituted in the regression model. The value of the fractional exponent was calculated from within the data by regressing the natural log (ln) of MWT + residual on ln (TDN + residual) [Hohenboken <u>et</u> <u>al</u>., 1976].

Multiple regression models used for respective periods were:

Period 1

$$\hat{Y}_i = \hat{B}_1(MWT) + \hat{B}_2(WTC) + \hat{B}_3(AOD) + \hat{B}_4(PP)$$

Period 2

$$\hat{Y}_i = \hat{B}_1(MWT) + \hat{B}_2(WTC) + \hat{B}_3(AOD)$$

Period 3

$$\hat{Y}_i = \hat{B}_1(MWT) + \hat{B}_2(WTC) + \hat{B}_3(AOD) + \hat{B}_5(MILK)$$

Cow Year

$$\hat{Y}_i = \hat{B}_1(MWT) + \hat{B}_2(WTC) + \hat{B}_3(AOD) + \hat{B}_5(MILK)$$

Heifer Year

$$\hat{Y}_i = \hat{B}_1(MWT) + \hat{B}_2(WTC)$$

where $\hat{Y}_i$ = total TDN consumed by the ith cow

$\hat{B}_1$ = the partial regression coefficient of MWT on TDN

$\hat{B}_2$ = the partial regression coefficient of WTC on TDN

$\hat{B}_3$ = the partial regression coefficient of AOD on TDN

$\hat{B}_4$ = the partial regression coefficient of PP on TDN

$\hat{B}_5$ = the partial regression coefficient of MILK on TDN

$\hat{B}_0$ = the predicted intercept and was included in the models for $MWT^{1.000}$ and MWT^{x} regression analysis.

Prediction equations for each of the three methods of multiple regression analysis were developed for cows using appropriate regression coefficients. Heifer year data were analyzed using only $MWT^{1.000}$ in the regression model. Daily TDN requirements were predicted for cows and heifers over a range of weights in respective stages of production.

INTRODUCTION

Economic pressure on beef producers necessitates critical evaluation of all production costs. The goal of cattlemen is to produce beef for the table by the most profitable method (O'Mary and Dyer, 1972). Feed constitutes the largest variable expense in the beef enterprise (Turner, 1974). Energy provided by feed can theoretically be divided into parts for maintenance of body weight, growth of body tissue and production of animal products (Hohenboken et al., 1972). Optimum performance of a cow is related to the proportion of energy utilized for each partition. Cow herd efficiency is extremely important, especially the energetic efficiencies of various cow sizes (Gregory, 1972; O'Mary and Dyer, 1972). Differences in overall efficiency of feed used may be due to differences in maintenance requirements or nutrient utilization. Knowledge of amounts of feed required for each use is needed to predict economic consequences of feeding and management systems (Hohenboken et al., 1972).

Although cow size has little effect on efficiency (Marshall et al., 1976), recent interest in larger cows suggests a need for an accurate method of predicting energy requirements for large and small cows during the different stages of production.

The objective of this study was to partition the energy intake of Angus, Charolais and reciprocal cross cows into maintenance, weight change and milk production requirements. Equations were developed to predict TDN requirements for beef cows and replacement heifers over a range of weights and during different stages of production.

EXPERIMENTAL PROCEDURES

Population

The population studied was described by Marshall et al. (1976). Experimental females were born in 1970-1972. Their dams were randomly selected Angus and 75% or higher Charolais cows from 58 cooperating producers across South Dakota. One Angus and one Charolais sire were artificially mated to the randomly selected dams to produce similar numbers of progeny in Angus, Angus x Charolais, Charolais x Angus and Charolais breed groups. At weaning, experimental females were randomly allotted to a pasture or drylot management system. Pasture females were managed under traditional summer grazing and winter feeding conditions. Drylot cows were randomly allotted by breed group to individual inside pens for feeding.

Herd management was consistent from year to year. All cows were bred artificially to calve first as 2-year-olds. One breed of sire represented by one sire was used each year. Sire breeds used during breeding seasons indicated were Polled Hereford (1971, 1972, 1973, 1977), Salers (1974), Limousin (1975) and Simmental (1976). Breeding seasons averaged 59 ± 4 days. Cows were removed from the project for infertility as heifers, failure to wean a calf 2 consecutive years, severe or repeated prolapse, death, unsoundness, temperament, double muscling or failure to produce milk. There were no differences (P>.05) in the rate of removal for breed groups or management systems. Mean cow weights by age and management system are given in figure 1.

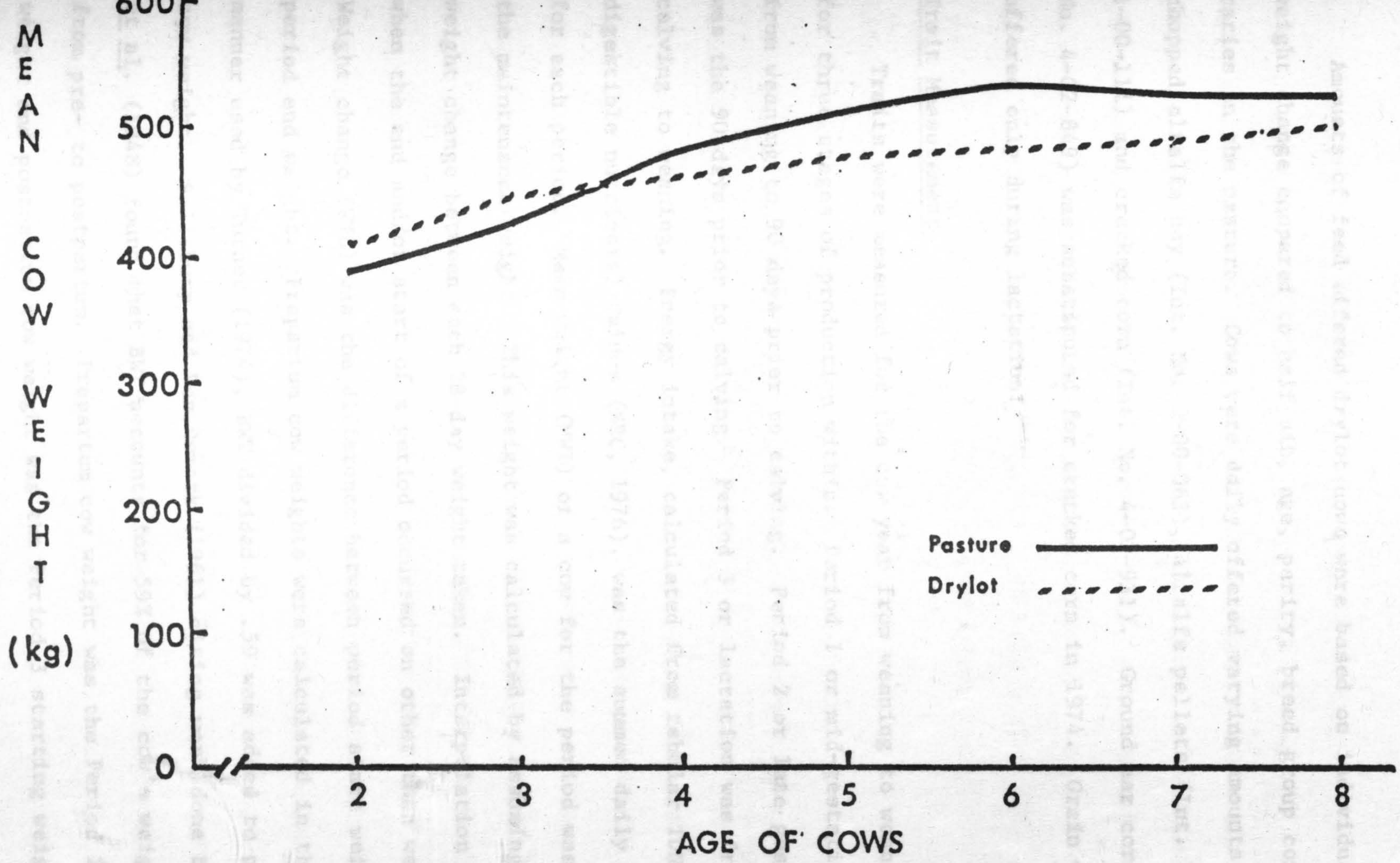

FIGURE 1. Mean weight of cows by age and management system.

Amounts of feed offered drylot cows were based on individual cow weight change compared to half sib, age, parity, breed group contemporaries in the pasture. Cows were daily offered varying amounts of chopped alfalfa hay (Int. No. 1-00-063), alfalfa pellets (Int. No. 1-00-111) and cracked corn (Int. No. 4-02-931). Ground ear corn (Int. No. 4-02-849) was substituted for cracked corn in 1974. Grain was offered only during lactation.

Trait Measurement

Traits were measured for the cow year from weaning to weaning and for three stages of production within. Period 1 or mid-gestation was from weaning to 90 days prior to calving. Period 2 or late gestation was the 90 days prior to calving. Period 3 or lactation was from calving to weaning. Energy intake, calculated from tabular TDN (total digestible nutrients) values (NRC, 1976), was the summed daily values for each period. Mean weight (MWT) of a cow for the period was used as the maintenance weight. This weight was calculated by assuming a linear weight change between each 28-day weight taken. Interpolation was when the end and/or start of a period occurred on other than weigh day. Weight change (WTC) was the difference between period start weight and period end weight. Prepartum cow weights were calculated in the same manner used by Turner (1974), BWT divided by .59 was added to postpartum cow weight. Salisbury and Van Demark (1961) citing work done by Swett et al. (1948) found that BWT accounts for 59% of the cow's weight change from pre- to postpartum. Prepartum cow weight was the Period 2 end weight and postpartum cow weight was the Period 3 starting weight. Milk production (MILK) was measured on 4 days spaced throughout the lactation cycle at approximately the same time each year using the calf weight change method (Neville, 1962; Totusek, 1974). Calves were weighed, allowed to nurse and reweighed at 700 and 1600 hours on the same day. MILK as used in the data analysis was the sum in kilograms of the four daily totals taken. Previous parity (PP) was coded 0 for open and 1 for cows weaning a calf the previous year. Future parity (FP) was coded 0 for open and 1 for cows calving the following year.

Data Analysis

The heifer year, cow year and three periods within the cow year were analyzed separately using least squares procedures with TDN as the dependent variable. Independent variables considered in Period 1 were MWT, WTC, age of dam in years (AOD), breed of dam (BOD), year (YR), PP, number of days in the period (DAYS) and all two factor interactions. BOD was coded 1 for Angus, 2 for Angus x Charolais, 3 for Charolais x Angus and 4 for Charolais cows. Period 2 independent variables were MWT, WTC, AOD, BOD, YR, PP, sex of calf (SEX), BWT and all two factor interactions. SEX was coded 1 for bulls and 2 for heifers. Independent variables considered in Period 3 were MWT, WTC, AOD, BOD, YR, FP, SEX, DAYS, MILK and all two factor interactions. Cow year independent variables included all previously considered except DAYS and interactions with DAYS. Variables considered in the heifer year were MWT, WTC, BOD, YR and DAYS. Three factor and higher order interactions were assumed nonsignificant.

Analyses of variance were used to eliminate nonsignificant variables (P>.25) using a step down procedure. Residuals calculated in the final analyses of variance models were used in the multiple regression analyses.

In the cow year and three periods within, multiple regression analyses were used to evaluate MWT by three different methods as one of the independent variables affecting TDN consumption. MWT as calculated ($MWT^{1.000}$), MWT to a fractional exponent (MWT^{x}) and MWT with the regression line forced through the origin (zero intercept) were substituted in the regression model. The exponent was calculated from the data by regressing the natural log (ln) of (MWT + residual) on ln (TDN + residual) [Hohenboken et al., 1972]. Daily TDN prediction equations were developed from regression coefficients for the three methods of analysis in the cow year and three periods within. Heifer year data were analyzed using the $MWT^{1.000}$ method with prediction equations developed for daily TDN requirements.

RESULTS AND DISCUSSION

Least squares means of the 284 cow year and 94 heifer year observations for each trait are given in table 4. Results indicate higher energy requirements for beef cows, especially smaller cows, than previously published. This is in agreement with an NRC (1976) suggestion to adjust published energy levels for specific environmental conditions. Hironaka and Peters (1969) in Canada, however, suggest published requirements are adequate, but compensatory gains were observed during summer grazing.

There was little difference between the use of $MWT^{1.000}$ and MWT^{x} in multiple regression analyses for predicting energy requirements. Forcing the regression line through the origin produced a steeper slope in all periods, suggesting biased estimates of energy requirements for small cows.

Analysis of each period and the cow year will be discussed including prediction equations developed from the three different methods of analyses. Heifer year analysis involved only the $MWT^{1.000}$ method of multiple regression analysis.

Period 1

Period 1 was 77.57 days long extending from late October to mid-January. MWT averaged 442.85 kg over all ages and breeds of dam. WTC averaged -.0327 kg per day. Cows consumed an average daily intake of 4.4669 kg TDN per cow.

TABLE 4. LEAST SQUARES MEANS OF VARIABLES

	Period				
Variable	Period 1[a]	Period 2[b]	Period 3[c]	Cow year	Heifer year
TDN[d]	4.4669	4.6638	7.2396	6.0463	4.9613
MWT[e]	442.8523	470.3116	451.6884	456.6519	282.93
MWT^x[f]	7.7198	12.4469	4.4981	2.8166	--
WTC[g]	-.0327	.6855	.1408	.0697	.5982
AOD[h]	4.2260	4.2276	4.3303	4.2239	--
PP[i]	.6067	--	--		--
MILK[j]	--	--	5.5751	5.4683	--
BWT[k,l]	--	37.9547	--	--	--
DAYS[l,m]	78	90	197	364	348

[a] Mid-gestation.
[b] Late gestation.
[c] Lactation.
[d] Daily total digestible nutrients.
[e] Mean weight of cows.
[f] Mean weight of cows to an exponent.
[g] Daily weight change of cows.
[h] Age of dam.
[i] Previous parity coded 0 for open and 1 for pregnant.
[j] Daily milk production estimate.
[k] Mean birth weight.
[l] Arithmetic means.
[m] Number of days in the period.

Variables influencing TDN consumption ($P<.25$) were MWT, WTC, AOD, PP, DAYS and YR. Variables in the final reduced model were DAYS and YR with residuals for TDN, MWT, WTC, AOD and PP used in multiple regression analyses.

The best single variable for predicting daily TDN requirements was AOD (table 5). WTC was added for the best two variable model. MWT entered the equation third followed by PP. Coefficient of determination was similar for the two, three and four variable model.

TABLE 5. PARTIAL REGRESSION COEFFICIENTS, COEFFICIENTS OF DETERMINATION AND STANDARD ERRORS OF ESTIMATE FOR DAILY TDN PREDICTION IN PERIOD 1 USING $MWT^{1.000}$

Equation number	Intercept	AOD	WTC	MWT	PP	R^2	SE
1	3.9577	.1205				.78	.6798
2	3.8279	.1539	.3744			.79	.6771
3	3.1305	.1306	.3853	.0018		.80	.6739
4	3.0034	.1162	.4403	.0020	.1668	.81	.6721

The intercept (table 5) is the TDN value where the y axis and an extension of the best fitting straight line intersect. This does not necessarily indicate TDN consumed at zero cow weight as zero weight is well beyond the range of the data analyzed.

Predicted daily TDN requirements were calculated using Equation 4 and plotted as $MWT^{1.000}$ (figure 2). Mean daily values for WTC and AOD were used to calculate TDN requirements for all weights plotted. Comparing predicted daily TDN requirements from this study with those of Neville (1974), Neville and McCullough (1969), NRC (1976) and Turner (1974) shows a large difference for lighter cows. Daily TDN requirements suggested by the present study are approximately 1.2 kg greater for a 400-kg cow than recommended by NRC (1976). Recommendations by other reports cited are within .6 kg of NRC (1976) for daily TDN for 400-kg cows (figure 2).

Climate possibly accounts for some of the variation. Lighter cows have more surface area per unit body weight, resulting in higher maintenance requirements in colder climates (Kleiber, 1961). NRC

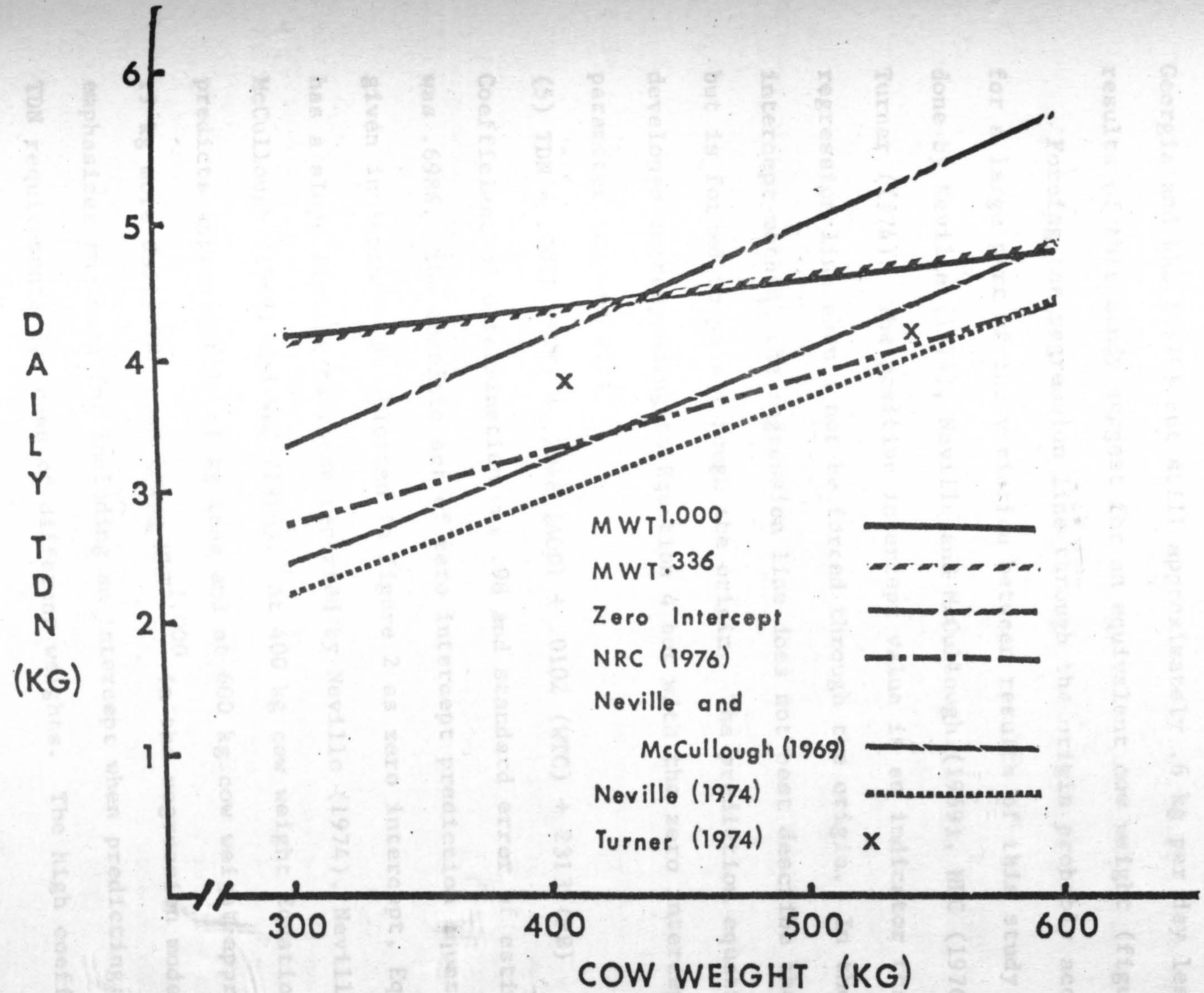

FIGURE 2. Predicted energy requirements for beef cows during mid gestation.

(1976) recommendations are directed to an average climate with adjustments suggested but not specified for extreme conditions. In Missouri, Turner (1974) found small cows (407 kg) have higher energy requirements than reported by Neville (1974) and Neville and McCullough (1969) in Georgia and NRC (1976) but still approximately .6 kg per day less than results of this study suggest for an equivalent cow weight (figure 2).

Forcing the regression line through the origin probably accounts for a large part of the variation between results of this study and work done by Neville (1974), Neville and McCullough (1969), NRC (1976) and Turner (1974). The positive intercept value is an indicator that the regression line should not be forced through the origin. In the zero intercept method, the regression line does not best describe the data but is forced to pass through the origin. The prediction equation developed corresponding to Equation 4 but with the zero intercept parameter imposed was:

$$(5)\ \hat{TDN} = .0079\ (MWT) + .2046\ (AOD) + .0102\ (WTC) + 2313\ (PP)$$

Coefficient of determination was .98 and standard error of estimate was .6986. The complete set of zero intercept prediction equations is given in Appendix B. Plotted in figure 2 as zero intercept, Equation 5 has a slope similar to those reported by Neville (1974), Neville and McCullough (1969) and NRC (1976). At 400 kg cow weight Equation 5 predicts approximately .1 kg less and at 600 kg cow weight approximately .9 kg more daily TDN than using $MWT^{1.000}$ in the regression model. This emphasizes the need for including an intercept when predicting daily TDN requirements for cows of different weights. The high coefficient of determination is misleading in that the correlation between predicted and observed TDN requirements is higher for $MWT^{1.000}$ predictions (table 6). It should be noted that R^2 values cannot be compared between analyses as different restrictions have been imposed. The coefficients of determination given for the zero intercept model are not the squared correlation between observed and predicted values, since they are derived from uncorrected sums of squares.

TABLE 6. CORRELATION COEFFICIENTS FOR OBSERVED AND PREDICTED TDN REQUIREMENTS FOR $MWT^{1.000}$ AND ZERO INTERCEPT METHODS OF ANALYSIS

	$MWT^{1.000}$	Zero intercept
Period 1	.238	.219
Period 2	.373	.363
Period 3	.325	.314

Using MWT^{x} was compared to using $MWT^{1.000}$ and zero intercept for predicting daily TDN requirements. An exponent of .336 was calculated for MWT during mid-gestation. This value is considerably lower than coefficients reported by Brody and Proctor (1935), Kleiber (1961) and Winchester and Hendricks (1953). In 1966, NRC adopted .75 as the exponent used with body weight to calculate metabolic weight. Manyard and Loosli (1975) refer to .75 as a practical value for the exponent. The exponent .336 is, however, within the range of values developed by other researchers who are cited by Thonney et al. (1976).

The difference in use of $MWT^{.336}$ and $MWT^{1.000}$ is small when comparing Equation 6 as follows with previously developed prediction equations (figure 2).

$$(6)\ \hat{TDN} = .8559 + .1240\ (AOD) + .0064\ (WTC) + .3905\ (MWT^{.336}) + .1709\ (PP)$$

Coefficient of determination was .82 and standard error of estimate was .6571. A complete set of prediction equations using $MWT^{.336}$ is given in Appendix C. Period 1 was also analyzed using $MWT^{.75}$. Standard error of estimate and coefficient of determination were .6610 and .82, respectively.

The comparisons made from Period 1 results strongly suggest that the estimates of daily TDN requirements for beef cows vary widely, depending on the method of analysis. Thonney et al. (1976) suggested that body weight would serve adequately as a covariable in predicting heat production. Results from Period 1 indicate body weight is useful for predicting total energy requirements but only if used with an appropriate intercept. The intercepts in table 5 are evidence that the best fitting straight line does not pass through the origin. Using $MWT^{.336}$ or $MWT^{.75}$ produced similar standard errors of estimate (Appendix A), suggesting either is appropriate when used with an intercept. However, this may not be true over the range of exponents summarized by Thonney et al. (1976). Forcing the regression line through the origin alters the predicted energy requirements by under-estimating TDN requirements for lighter cows and overestimating for heavier cows.

Period 2

During the last 90 days of gestation from approximately mid-January to mid-April, cow weights averaged 470.3116 kilograms. The average WTC was .6855 kg per day. Cows consumed an average of 4.6638 kg of TDN per cow per day.

Variables influencing TDN ($P<.25$) were MWT, WTC, AOD, YR, BOD and SEX. Variables in the final reduced model were YR, BOD and SEX with residuals for TDN, MWT, WTC and AOD used in multiple regression analysis. Two interactions, AOD*YR and BWT*AOD, also affected TDN consumption but were not used in predicting TDN as YR effects and BWT could not be measured at the time of prediction.

WTC was the best single variable for predicting daily TDN requirements, probably due to late gestation gains. AOD was added as the second variable and MWT entered the equation third (table 7).

TABLE 7. PARTIAL REGRESSION COEFFICIENTS, COEFFICIENTS OF DETERMINATION AND STANDARD ERRORS OF ESTIMATE FOR DAILY TDN PREDICTION IN PERIOD 2 USING $MWT^{1.000}$

Equation number	Intercept	WTC	AOD	MWT	R^2	SE
7	4.1887	.6933			.64	.5460
8	3.5312	.6646	.1599		.68	.5333
9	2.5317	.6719	.1390	.0023	.70	.5293

TDN requirements calculated from Equation 9 were plotted in figure 3 as $MWT^{1.000}$. Mean daily values for WTC and AOD were used to calculate TDN requirements for plotted values. Coefficients of

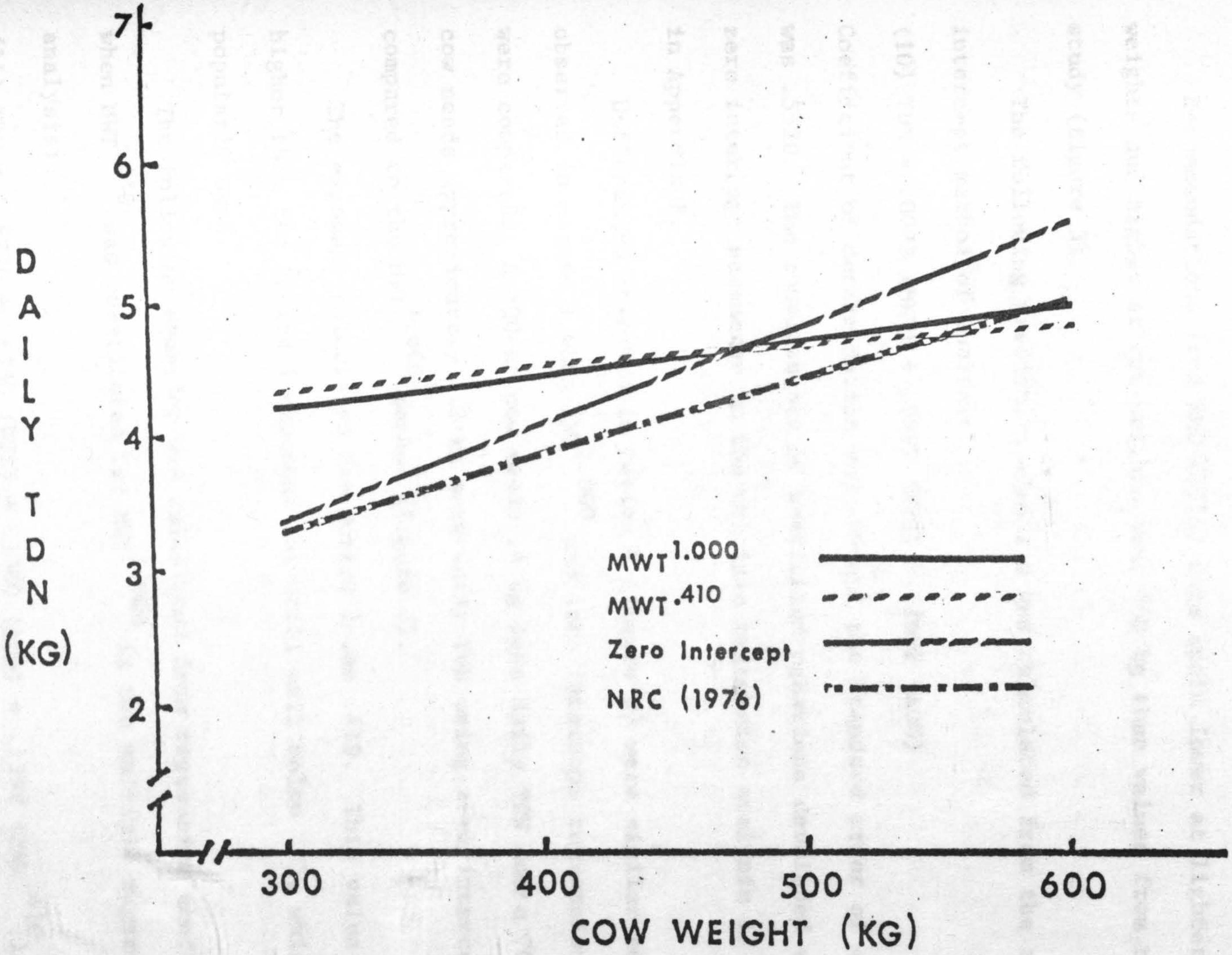

FIGURE 3. Predicted energy requirements for beef cows during late gestation.

determination increased from .64 in the single variable model to .70 when all three variables were included, with little difference between Equations 8 and 9.

Recommendations from NRC (1976) were again lower at lighter cow weights and higher at cow weights over 600 kg than values from this study (figure 3).

The following prediction equation was calculated from the zero intercept method of analysis:

(10) $\hat{TDN} = .0073\ (MWT) + .0089\ (WTC) + .1662\ (AOD)$

Coefficient of determination was .99 and the standard error of estimate was .5520. The complete set of prediction equations developed using a zero intercept parameter in the multiple regression analysis is given in Appendix E.

Differences observed in Period 2 (figure 3) were similar to those observed in Period 1 when $MWT^{1.000}$ and zero intercept regression lines were compared. A 400-kg cow needs .4 kg less daily TDN and a 700-kg cow needs approximately 1.2 kg more daily TDN using zero intercept compared to the $MWT^{1.000}$ method (figure 3).

The exponent calculated for Period 2 was .410. This value is higher than the Period 1 exponent but still well below .75, which is popularly used.

The following equation was calculated from regression coefficients when $MWT^{.410}$ was substituted for $MWT^{1.000}$ in the multiple regression analysis:

(11) $\hat{TDN} = 1.8776 + .6730\ (WTC) + .1380\ (AOD) + .1398\ (MWT^{.410})$

Coefficient of determination was .70 and standard error of estimate was .5291. Appendix F contains a complete set of prediction equations developed using $MWT^{.410}$. Predicted daily TDN requirements were .5 to .9 kg lower using $MWT^{.410}$ compared to $MWT^{1.000}$ (figure 3).

Period 2 results support the conclusions from Period 1. Zero intercept again artificially increases the regression line slope. Environment may account for some of the differences between Period 2 results and NRC (1976) recommendations. Using $MWT^{.410}$ is the preferred method for predicting TDN in Period 2.

Period 3

The lactation period averaged 197.78 days long, extending from mid-April to late October. Cows averaging 451.6884 kg consumed an average of 7.2396 kg TDN per day. WTC averaged .1408 kg daily gain. MILK averaged 5.5751 kg daily from the four daily totals.

Variables affecting TDN in Period 3 were MWT, WTC, AOD, MILK and DAYS. The variable in the final reduced model was DAYS with residuals from TDN, MWT, WTC, AOD and MILK used in multiple regression analysis.

The best single variable for predicting daily TDN requirements during lactation was MWT with an R^2 value of .44 (table 8). MILK was included in the best two variable model followed by AOD and WTC. Coefficient of determination increased from .44 to .46 for the two, three and four variable models. However, the standard error of estimate was lowest for Equation 13 (table 8). Equation 13 was used to calculate the requirements plotted in figure 4 as $MWT^{1.000}$. Results suggest TDN requirements were higher than values reported by Hohenboken et al. (1972),

TABLE 8. PARTIAL REGRESSION COEFFICIENTS, COEFFICIENTS OF DETERMINATION AND STANDARD ERRORS OF ESTIMATE FOR DAILY TDN PREDICTION IN PERIOD 3 USING $MWT^{1.000}$

Equation number	Intercept	MWT	MILK	AOD	WTC	R^2	SE
12	4.8005	.0054				.44	.8077
13	4.5926	.0047	.0942			.46	.7995
14	4.7300	.0043	.0834	.0239		.46	.8000
15	4.7015	.0042	.0880	.0286	.1858	.46	.8014

Neville (1974) and Neville and McCullough (1969). Differences are possibly due to climate or forcing the regression line through the origin or both. Climatic differences would be minimized during the summer months of the lactation period.

The total amount of energy required for lactation is proportional to the amount of milk produced, varying slightly with fat content. Neville and McCullough (1969) suggest that maintenance requirements increase approximately 30% during lactation. This may be due to repair of tissue in the reproductive tract and maintenance of the producing mammary system. Daily energy requirements for cows in this study were approximately 2.1 kg greater than NRC (1976) recommendations for 500-kg cows of average milking ability. The greater daily energy requirement would result in a smaller partial regression coefficient for MILK if the increase in energy requirement was due mostly to maintenance.

The zero intercept prediction equation with the lowest standard error of estimate for Period 3 was:

(16) $\hat{TDN}$ = .0140 (MWT) + .1972 (MILK) - .0811 (AOD) + .6887 (WTC)

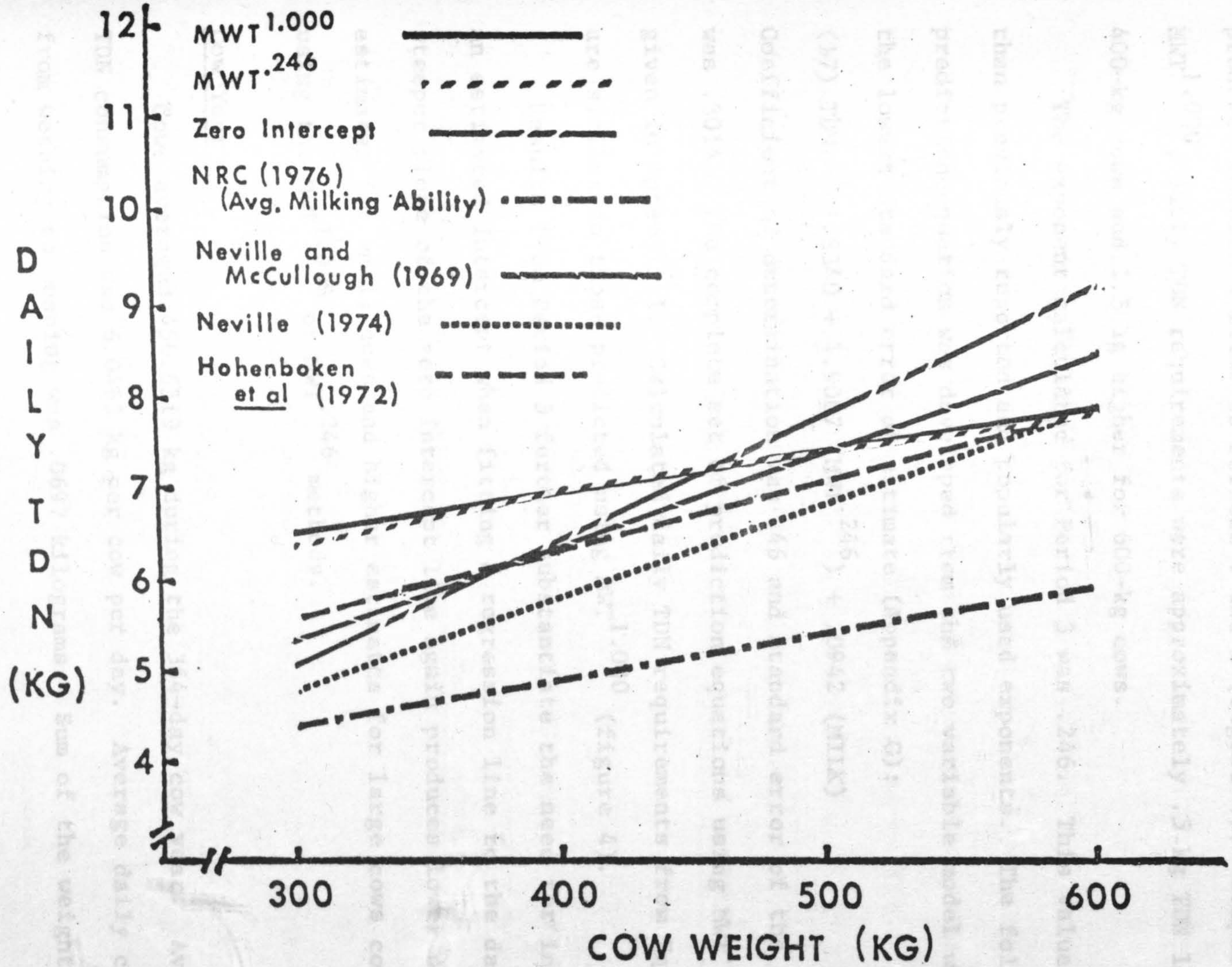

FIGURE 4. Predicted energy requirements for beef cows during lactation.

Coefficient of determination was .98 and standard error of estimate was .8940. The complete set of zero intercept equations for lactation is given in Appendix H. Forcing the regression line through the origin produced results similar to Periods 1 and 2 (figure 4). Compared to $MWT^{1.000}$, daily TDN requirements were approximately .5 kg TDN lower for 400-kg cows and 1.3 kg higher for 600-kg cows.

The exponent calculated for Period 3 was .246. This value is lower than previously reported and popularly used exponents. The following prediction equation was developed from the two variable model which had the lowest standard error of estimate (Appendix G):

$$(17)\quad \hat{TDN} = -1.8340 + 1.9007\,(MWT^{.246}) + .0942\,(MILK)$$

Coefficient of determination was .46 and standard error of the estimate was .8014. The complete set of prediction equations using $MWT^{.246}$ is given in Appendix I. Calculated daily TDN requirements from Equation 17 are similar to those predicted using $MWT^{1.000}$ (figure 4).

Results from Period 3 further substantiate the need for including an estimated intercept when fitting a regression line to the data. The steeper slope of the zero intercept line again produces lower daily TDN estimates for small cows and higher estimates for large cows compared to using the $MWT^{1.000}$ or $MWT^{.246}$ methods.

Cow Year

Cows averaged 456.6519 kg during the 364-day cow year. Average TDN consumption was 6.0463 kg per cow per day. Average daily cow gain from weaning to weaning was .0697 kilograms. Sum of the weight changes for the three periods was 85.41 kg per cow with an average of 64.33 kg lost during calving.

Variables influencing TDN ($P<.25$) during the cow year were MWT, WTC, AOD, MILK and BOD. Variables in the final reduced model were YR and BOD with residuals for TDN, MWT, WTC, AOD and MILK used in multiple regression analysis.

Prediction equations were developed and plotted for the cow year as a matter of interest and to compare methods of analysis rather than to provide specific estimates of daily TDN requirements. MILK was the best single variable for predicting TDN. MWT was added for the best two variable model followed by AOD and WTC (table 9). There was little difference in the standard error of estimate for Equations 19, 20 and 21. Values from Equation 20 are plotted in figure 5 as $MWT^{1.000}$.

TABLE 9. PARTIAL REGRESSION COEFFICIENTS, COEFFICIENTS OF DETERMINATION AND STANDARD ERRORS OF ESTIMATE FOR DAILY TDN PREDICTION IN THE COW YEAR USING $MWT^{1.000}$

Equation number	Intercept	MILK	MWT	AOD	WTC	R^2	SE
18	5.5979	.0820				.64	.5002
19	4.4587	.0732	.0026			.67	.4939
20	4.4701	.0720	.0022	.0421		.67	.4952
21	4.3603	.0736	.0023	.0486	.4044	.67	.4954

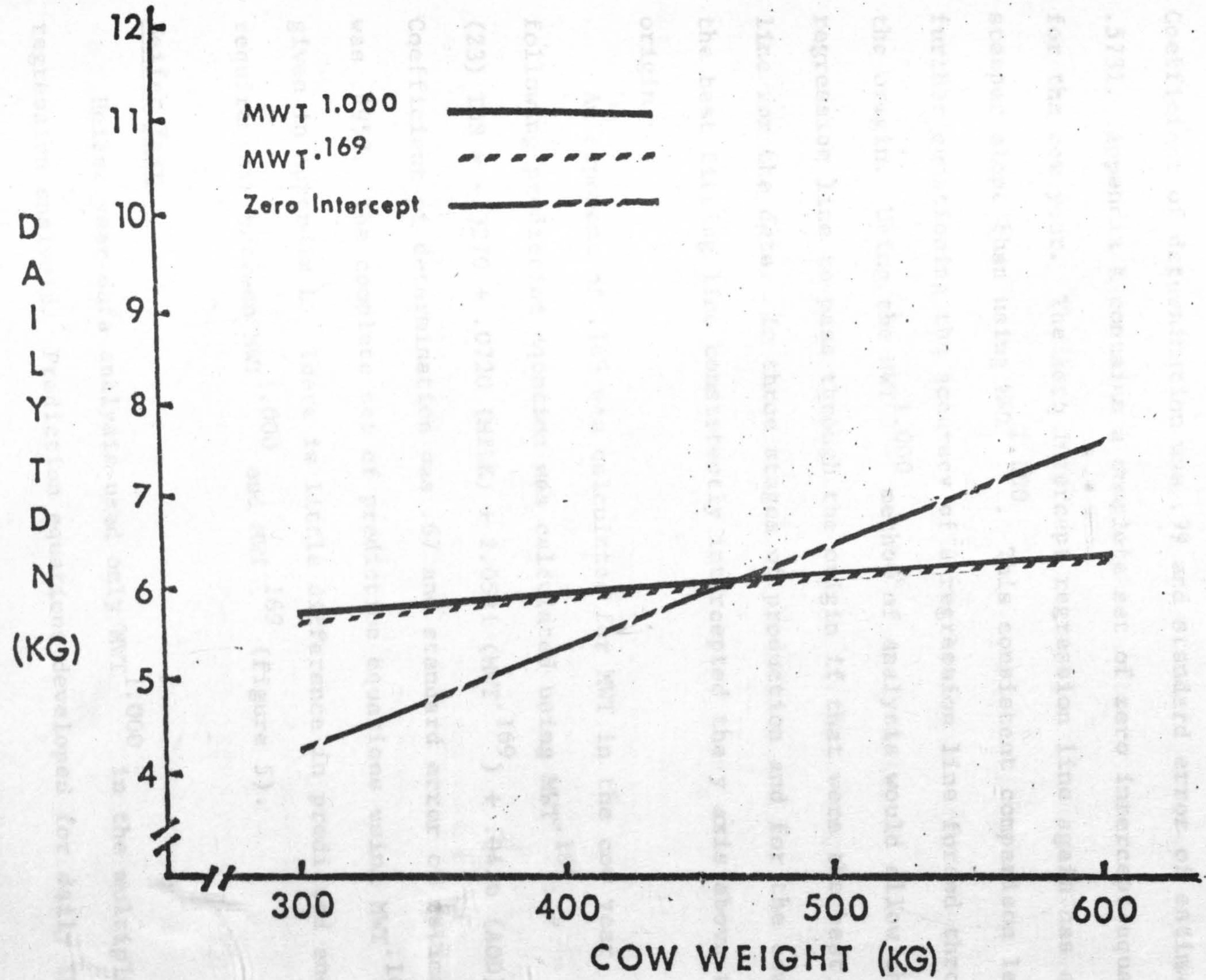

FIGURE 5. Predicted energy requirements for beef cows during the cow year.

Analysis using the zero intercept parameter resulted in the following two variable equation which had the lowest standard error of estimate:

(22) $\hat{TDN} = .0117\ (MWT) + .1256\ (MILK)$

Coefficient of determination was .99 and standard error of estimate was .5731. Appendix K contains a complete set of zero intercept equations for the cow year. The zero intercept regression line again has a much steeper slope than using $MWT^{1.000}$. This consistent comparison leads to further questioning the accuracy of a regression line forced through the origin. Using the $MWT^{1.000}$ method of analysis would allow the regression line to pass through the origin if that were the best fitting line for the data. In three stages of production and for the cow year, the best fitting line consistently intercepted the y axis above the origin.

An exponent of .169 was calculated for MWT in the cow year. The following prediction equation was calculated using $MWT^{.169}$:

(23) $\hat{TDN} = -.3270 + .0720\ (MILK) + 2.0591\ (MWT^{.169}) + .0426\ (AOD)$

Coefficient of determination was .67 and standard error of estimate was .4952. The complete set of prediction equations using $MWT^{.169}$ are given in Appendix L. There is little difference in predicted energy requirements between $MWT^{1.000}$ and $MWT^{.169}$ (figure 5).

Heifer Year

Heifer year data analysis used only $MWT^{1.000}$ in the multiple regression analysis. Prediction equations developed for daily TDN requirements and coefficients of determination were:

(24) $\hat{TDN} = 1.2507 + .0131\ (MWT)$

(25) $\hat{TDN} = 1.7570 + .0113\ (MWT) + 1.6125\ (WTC)$

Coefficient of determination increased from .62 in Equation 24 to .69 in Equation 25. Standard error of estimate decreased from .3211 to .2939 kilograms. Equation 25 is plotted in figure 6 for heifers ranging in weight from 200 kg to 375 kilograms. NRC (1976) recommends approximately .8 kg less daily TDN for heifers weighing 200 kg to 375 kilograms than suggested by this study for equivalent weight gains (figure 6). This indicates a need for more energy in colder climates for replacement heifers than recommended. The slope of the regression line developed is similar to the recommended energy levels (NRC, 1976).

General Conclusions

Results of this study indicate energy requirements need to be increased from NRC (1976) recommendations for beef cows and growing heifers. Recognizing that recommendations cannot be published to fit all environments, cattlemen need to adjust rations for specific conditions. Results suggest a need for more accuracy in estimating these ration adjustments.

Estimated TDN requirements were greatly influenced by method of analysis. Considerable variation in estimates resulted from using two of the three techniques evaluated. $MWT^{1.000}$ and MWT^{x} used in multiple regression analysis produced similar results. The value of the exponent appears to have little impact on the standard error of estimate and predicted TDN requirements provided an appropriate intercept is used.

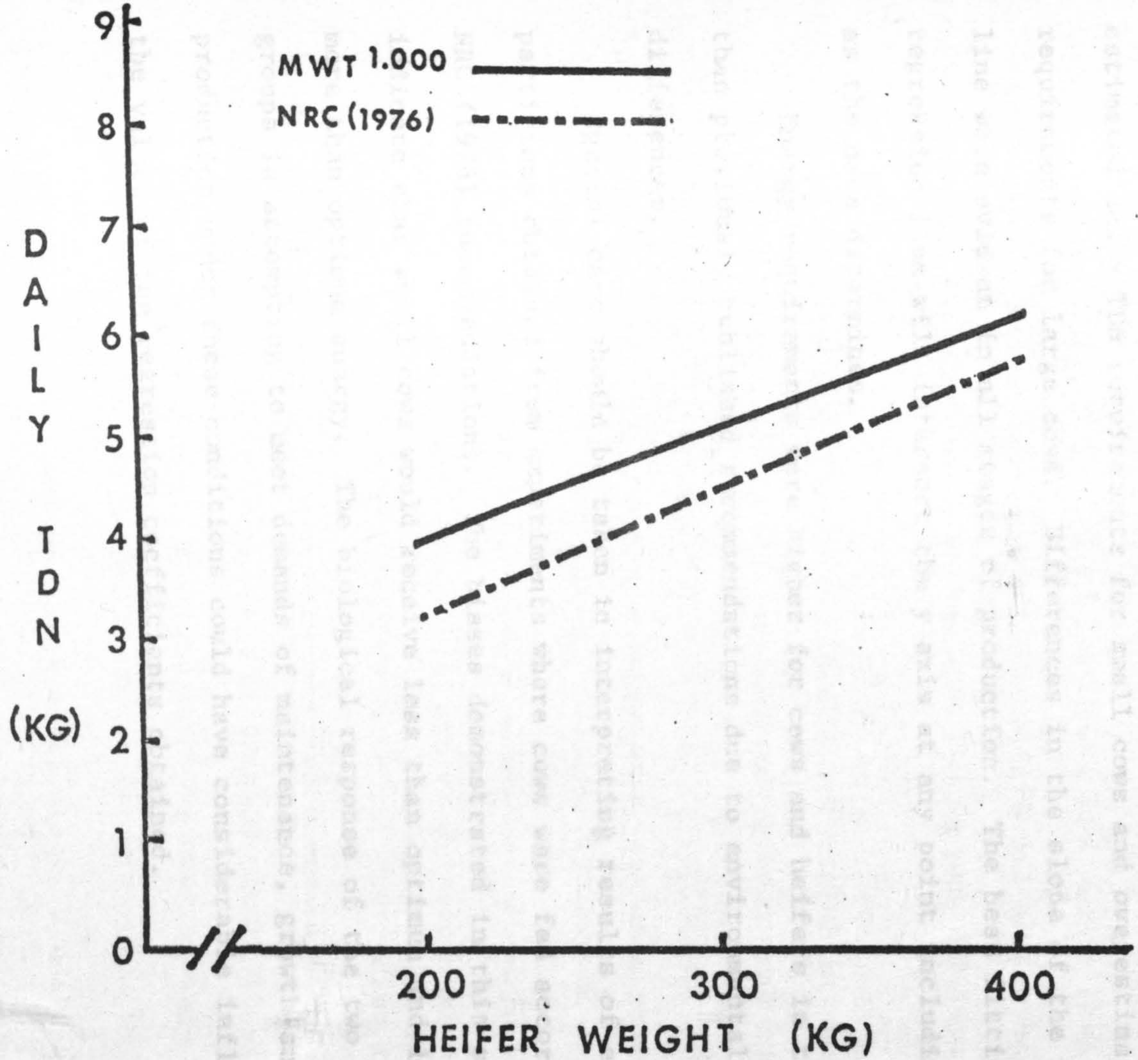

FIGURE 6. Predicted energy requirements for replacement heifers.

Results of this study support Thonney et al. (1976) in recommending $MWT^{1.000}$ as a variable for predicting energy requirements. MWT^{x} is slightly preferred providing it is used with an intercept.

Forcing the regression line through the origin repeatedly underestimated daily TDN requirements for small cows and overestimated TDN requirements for large cows. Differences in the slope of the regression line were evident in all stages of production. The best fitting regression line will intersect the y axis at any point including zero as the data determines.

Energy requirements were higher for cows and heifers in this study than previously published recommendations due to environmental differences.

Special care should be taken in interpreting results of energy partitions obtained from experiments where cows were fed according to NRC (1976) recommendations. The biases demonstrated in this study indicate that small cows would receive less than optimum and large cows more than optimum energy. The biological response of the two extreme groups in attempting to meet demands of maintenance, growth and milk production under these conditions could have considerable influence on the values of the regression coefficients obtained.

SUMMARY

Energy consumed in 284 cow years by individually fed Angus, Charolais and reciprocal cross cows was partitioned into maintenance, weight change and milk production requirements. TDN consumed in 94 heifer years was partitioned into maintenance and weight change requirements. The cow year was subdivided into mid-gestation, late gestation and lactation periods that were 78, 90 and 197 days long, respectively.

Variables affecting TDN intake ($P<.25$) and useful in predicting daily energy requirements in all periods studied were mean body weight (MWT), weight change (WTC) and age of dam (AOD). Previous parity (PP) influenced TDN consumption during mid-gestation and milk production (MILK) influenced TDN consumption during lactation.

MWT was evaluated by three methods as one of the variables influencing TDN consumption. $MWT^{1.000}$, MWT to a fractional exponent (MWT^{x}) calculated from the data and MWT with the regression line forced through the origin (zero intercept) were substituted in the multiple regression model. Daily TDN prediction equations were developed from regression coefficients for cows over a range of weights.

Results indicate method of analysis influences predicted daily TDN requirements. Use of $MWT^{1.000}$ and MWT^{x} resulted in similar predictions, while the zero intercept technique underestimated energy requirements for small cows and overestimated energy requirements for large cows.

Accurate estimates are obtained from the best fitting regression line which intersects the y axis at the point determined by the data which may include zero.

Cows and heifers in this study required more energy than previously published recommendations due to environmental influences.

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APPENDIX

A. STANDARD ERRORS OF ESTIMATE AND COEFFICIENTS OF DETERMINATION FOR PERIOD 1 MULTIPLE REGRESSION ANALYSIS

Number of variables	$MWT^{1.000}$		Zero intercept		$MWT^{.336}$		$MWT^{.75}$	
	R^2	SE	R^2	SE	R^2	SE	R^2	SE
1	.78	.6798	.97	.7270	.79	.6667	.79	.6667
2	.80	.6771	.98	.7156	.80	.6630	.80	.6630
3	.81	.6739	.98	.6993	.81	.6594	.81	.6594
4	.82	.6721	.98	.6948	.82	.6571	.82	.6576

B. PREDICTION EQUATIONS FOR KG DAILY TDN DURING MID-GESTATION (PERIOD 1) USING ZERO INTERCEPT

	R^2
$\widehat{TDN}$ = .0101 (MWT)	.97
$\widehat{TDN}$ = .0084 (MWT) + .1767 (AOD)	.98
$\widehat{TDN}$ = .0800 (MWT) + .2273 (AOD) + .7241 (WTC)	.98
$\widehat{TDN}$ = .0079 (MWT) + .2046 (AOD) + .7983 (WTC) + .2313 (PP)	.98

C. PREDICTION EQUATIONS FOR KG DAILY TDN DURING MID-GESTATION (PERIOD 1) USING $MWT^{.336}$

	R^2
$\hat{TDN} = 3.9655 + .1222\ (AOD)$	.79
$\hat{TDN} = 3.8205 + .1595\ (AOD) + .3876\ (WTC)$	.80
$\hat{TDN} = .9943 + .1380\ (AOD) + .4426\ (WTC) + .3781\ (MWT^{.336})$	.81
$\hat{TDN} = .8559 + .1240\ (AOD) + .4985\ (WTC) + .3905\ (MWT^{.336}) + .1709\ (PP)$	.82

D. STANDARD ERRORS OF ESTIMATE AND COEFFICIENTS OF DETERMINATION FOR PERIOD 2 MULTIPLE REGRESSION ANALYSIS

Number of variables	$MWT^{1.000}$		Zero intercept		$MWT^{.410}$	
	R^2	SE	R^2	SE	R^2	SE
1	.64	.5458	.98	.5973	.64	.5458
2	.69	.5331	.99	.5649	.69	.5331
3	.70	.5294	.99	.5520	.70	.5303

E. PREDICTION EQUATIONS FOR KG DAILY TDN DURING LATE GESTATION (PERIOD 2) USING ZERO INTERCEPT

	R^2
$\hat{TDN} = .0098\ (MWT)$	.98
$\hat{TDN} = .0087\ (MWT) + .8435\ (WTC)$	.99
$\hat{TDN} = .0073\ (MWT) + .7991\ (WTC) + .1662\ (AOD)$	.99

F. PREDICTION EQUATIONS FOR KG DAILY TDN DURING LATE GESTATION (PERIOD 2) USING $MWT^{.410}$

	R^2
$\hat{TDN} = 4.1887 + .6933\ (WTC)$	.64
$\hat{TDN} = 3.5317 + .6646\ (WTC) + .1598\ (AOD)$	.68
$\hat{TDN} = 1.8776 + .6730\ (WTC) + .1380\ (AOD) + .1398\ (MWT^{.410})$	.70

G. STANDARD ERRORS OF ESTIMATE AND COEFFICIENTS OF DETERMINATION FOR PERIOD 3 MULTIPLE REGRESSION ANALYSIS

Number of variables	$MWT^{1.000}$		Zero intercept		$MWT^{.246}$	
	R^2	SE	R^2	SE	R^2	SE
1	.44	.8088	.98	.9283	.43	.8098
2	.46	.8002	.98	.9089	.46	.8014
3	.46	.8010	.98	.8968	.46	.8021
4	.46	.8020	.99	.8940	.46	.8031

H. PREDICTION EQUATIONS FOR KG DAILY TDN DURING LACTATION (PERIOD 3) USING ZERO INTERCEPT

	R^2
$\hat{TDN} = .0158\ (MWT)$	.98
$\hat{TDN} = .0141\ (MWT) + .1447\ (MILK)$	.98
$\hat{TDN} = .0146\ (MWT) + .1837\ (MILK) - .1031\ (AOD)$	.98
$\hat{TDN} = .0140\ (MWT) + .1972\ (MILK) - .0811\ (AOD) + .6980\ (WTC)$	.99

I. PREDICTION EQUATIONS FOR KG DAILY TDN DURING LACTATION (PERIOD 3) USING $MWT^{.246}$

	R^2
$\hat{TDN} = -2.6279 + 2.1937\ (MWT^{.246})$	.43
$\hat{TDN} = -1.8340 + 1.9007\ (MWT^{.246}) + .0942\ (MILK)$	.46
$\hat{TDN} = -.9833 + 1.7010\ (MWT^{.246}) + .0827\ (MILK) + .0254\ (AOD)$	.46
$\hat{TDN} = -.9389 + 1.6749\ (MWT^{.246}) + .0874\ (MILK) + .0302\ (AOD)$	
$+ .1877\ (WTC)$	.46

J. STANDARD ERRORS OF ESTIMATE AND COEFFICIENTS OF DETERMINATION FOR THE COW YEAR MULTIPLE REGRESSION ANALYSIS

Number of variables	$MWT^{1.000}$		Zero intercept		$MWT^{.169}$	
	R^2	SE	R^2	SE	R^2	SE
1	.64	.5004	.98	.5891	.64	.5004
2	.67	.4952	.98	.5731	.67	.4955
3	.67	.4952	.98	.5658	.67	.4954
4	.67	.4954	.98	.5651	.67	.4956

K. PREDICTION EQUATIONS FOR KG DAILY TDN DURING THE COW YEAR USING ZERO INTERCEPT

	R^2
$\hat{TDN}$ = .0132 (MWT)	.99
$\hat{TDN}$ = .0117 (MWT) + .1256 (MILK)	.99
$\hat{TDN}$ = .0114 (MWT) + .1276 (MILK) + 1.4193 (WTC)	.99
$\hat{TDN}$ = .0109 (MWT) + .1260 (MILK) + 1.5310 (WTC) + .0627 (AOD)	.99

L. PREDICTION EQUATIONS FOR KG DAILY TDN DURING THE COW YEAR USING $MWT^{.169}$

	R^2
$\hat{TDN}$ = 5.5979 + .0820 (MILK)	.64
$\hat{TDN}$ = −1.1845 + .0732 (MILK) + 2.4251 ($MWT^{.169}$)	.67
$\hat{TDN}$ = −.3270 + .0720 (MILK) + 2.0591 ($MWT^{.169}$) + .0426 (AOD)	.67
$\hat{TDN}$ = −.6827 + .0736 (MILK) + 2.1626 ($MWT^{.169}$) + .0491 (AOD)	
+ .4004 (WTC)	.67